Supplementary TEXT S2 Vit et al. biblio SBH 2023

Mapping six decades of stingless bee honey research: Chemical quality and Bibliometrics

Patricia Vit, Temitope Cyrus Ekundayo, Zhengwei Wang

Theme maps cluster the importance and stage of development using KeyWords Plus

The theme map for publications on chemical quality of pot-honey or stingless bee honey research (1962-2022) in Figure S6 was a co-occurrence network of the KeyWords Plus. Clusters are classified in terms of importance of themes –centrality measure of the cluster– and theme status of development –density of connections within clusters– (Tay, 2022). The X-axis represents a cluster interaction about the importance or relevance degree of a theme (centrality). The Y-axis is on the strength of a cluster network (density) for the theme's development. Four types of themes were mapped: 1. The first quadrant (upper right) motor themes are the well-developed and important themes of a research field, 2. The second quadrant (upper left) plotted highly developed but isolated themes of limited importance, 3. The third quadrant contains emerging or declining themes weakly developed and marginal, and 4. The fourth quadrant (lower right) with basic themes transversal to different research fields.

Our dataset generated a motor theme on bioactivity in the upper right quadrant, with clustered antioxidant, antimicrobial, and antibacterial activities. Moving to the left upper quadrant, the niche themes were composed by two distinctive clusters. One included the recently discovered sugar trehalulose, abundant in pot-honeys of some stingless bee species, and the sugar erlose with the ion chromatographer. Indeed, none of these two sugars were considered as reference standards of targeted ^{1}H-NMR. The reference sample for quantification in food applications used for the NMR mixture analysis in combination with Bruker-profiling was designed for 36 metabolites, consisting of ten sugars, but trehalulose was a recent discovery, thus was not included (Vit et al., 2023). The second niche theme was unexpected on apidae, tool use and hymenoptera. This would need further analysis since Hymenoptera is the order and Apidae is the largest family –of the superfamily Apoidea– where Apini and Meliponini tribes belong to the subfamily Apinae. In the third quadrant, emerging or declining themes were expected with either maturing or vanishing tendencies of incipient or contracting growth. Only one cluster for food composition, food analysis and physicochemical characteristics. The semantics between physicochemical characteristics and properties found in a cluster of the following quadrant, are subtle, but properties may be more related to functionality, which surprisingly was not surfaced in the theme map. The basic themes were represented by two core clusters in the fourth lower-right quadrant: The first for stingless bee(s) and honey, as included in the query strings for the Scopus database retrieval, and the second cluster was elemental for the research accomplished so far on physicochemical and antioxidant characterization. Pot-honey was not adopted by researchers for thinking on honey transformations in the stingless bee nest. However, new discoveries on the cerumen composition of honey pots and pollen pots are waiting for integrative comprehension of physicochemical and microbial dynamics in the meliponine resin-beeswax-based materials.

Topic dendrogram by HCA of the author's keywords

In Figure S7 a topic dendrogram was built by Hierarchical Cluster Analysis (HCA) of the author's keywords. The topic to the left (pink) clustering bee taxa was segmented from the large blue cluster to the right, further divided into two clusters. The first set of documents on bioactivity, microbes, physical chemistry, stingless bee and propolis; and the second on phenols, antioxidants, moisture, carbohydrates, bee, bees, including one country Brazil. The first blu cluster was further divided into one with the antibacterial, antimicrobial, and antioxidant activities, two pathogenic microorganisms *Escherichia coli* and *Staphylococcus aureus* obviously used for the antibacterial or antimicrobial activities, and flavonoids more related with the antioxidant activity. Here we started to note an unfamiliar keyword generated in the Scopus database but not used by authors: Unclassified drugs. In the second subcluster, other of those words were noted: controlled study, nonhuman, and article. We observed those non related keywords in other studies of diverse nature, just exclude them from our analysis. Here, stingless bee –that should have been positioned in the pink cluster– antinfective agent, high performance liquid chromatography, and physical chemistry were clustered together. In the third cluster, the keywords unfamiliar for the retrieved dataset are animal, animals, female, and male. These words have been a recurrent observation in the Scopus database, of no interest in the factorial analysis. Hexapoda was another peculiar keyword created by the

Scopus database, not present in authors' keywords, observed in another bibliometric study (P Vit, unpublished data).

Conceptual map by MCA of the author's keywords

Both the dendrogram and the conceptual map are Bibliometrix tools of factorial analysis. They use different statistical methods; the conceptual map is based on Multiple Correspondence Analysis (MCA). The co-word analysis is used to map the conceptual structure of a framework. The word co-occurrences in a bibliographic collection are used to draw a conceptual structure of the field and K-means clustering to identify clusters of documents having common concepts. Results are plotted on a two-dimensional map[21]. The structure provided by the conceptual map of authors' keywords in Figure S8, showed two clusters. A small blue one on bees: honeybee, apis.mellifera, tetragonisca.angustula, meliponinae, hymenoptera, apoidea, apidae, scaptotrigona.postica, and melipona. The largest pink map has several unfamiliar author's keywords, and those related with the chemical composition of honey (carbohydrates, flavonoids, moisture), active compounds (antioxidant, antioxidants, flavonoids, phenols, phenol.derivatives), bioactivity (antioxidant.activity, antibacterial.activity, antimicrobial.activity), pathogenic microbes (escherichia.coli, staphylococcus.aureus), bee products (honey, food.products, pollen, propolis), scientific disciplines (physical.chemistry, chemistry, physiology), and equipment (high.performance.liquid-chromatography). Some of these authors' keywords would have been expected to bee clustered in the blue map bee, bees, and stingless bees.

Most active institutions in chemical quality of pot-honey or stingless bee honey research (1962-2022)

In Table SIII were recorded that the top 10 most active institutions in pot-honey research were universities from Malaysia –half of them– Brazil, Venezuela, and Indonesia. The top three universities were Universiti Putra Malaysia, Universidade de São Paulo from Brazil, and Universidad de Los Andes from Venezuela.

Most productive countries in chemical quality of pot-honey or stingless bee honey research (1962-2022)

Table SIV shows the ranking of the top 10 most productive countries for pot-honey research (1962-2022): 1. Brazil, 2. Malaysia, 3. Mexico, 4. United States of America, 5. Indonesia, 6. Venezuela, 7. United Kingdom, 8. Australia, 9. Germany, and 10. Thailand. A worldwide map shows connectors between countries that have collaborated for research on stingless bee honey and shared more than two papers (Figure S9). This is the social structure variable of Bibliometrix. Connectors do not show countries with less than three shared papers. Germany and Australia have the thicker connector for stingless bee honey research. The collaborative frequencies ranked 10 between Brazil and Germany, 9 between Australia and Venezuela, 8 between Venezuela and Spain, 7 between Brazil and Portugal, 6 between the United States and Thailand, as well as Malaysia and the United Kingdom, Malaysia and China, Brazil and Venezuela, 5 between Venezuela and Italy, 4 between Netherlands and Costa Rica, Malaysia and China, Indonesia and Japan, Australia and Japan. Brazil and Austria, Australia, and Canada, 3 between Mexico and the United Kingdom and Cuba, Thailand and Japan, the United States and Panama, Venezuela and Switzerland. The Australia and Venezuela, Venezuela and Spain collaborative report in this map was in agreement with three-node cluster 8 for tomás-barberán fa from Spain, vit p from Venezuela, and heard ta from Australia, in Figure S3 visualization of co-authors' collaborative networks.

The three-field-plot is the last option of the variable dataset in the Bibliometrix Biblioshiny interphase, with diverse field tags available. The data frame columns were codified using the standard Clarivate Analytics WoS Field Tags. In Figure S10 a graph was plotted based on rankings of AU-UN author´s university, AU author, and AU-CO author's country. The parameters selected here were 20 authors for the middle field, 15 author's affiliations for the left field, and 15 author's countries for the right field. The gray bands show the authors' affiliations and their international collaborations sharing published documents of each author in the dataset on chemical quality of pot-honey or stingless bee honey research (1962-2022).

Major journal and book source titles used to disseminate pot-honey or stingless bee honey research

Journal choice is a strategic decision. Diverse factors affect a smooth and efficient editorial process. First of all the integrity of the editor is a basic quality. Scientists need confidence, useful and reliable feedback from reviewers (Rowley et al., 2022). In Table SV were listed the top ten relevant sources for pot-honey publications. The *Journal of Apicultural Research* hosted most documents (31), the book *Pot-Honey. A Legacy of Stingless Bees* (25), and *Apidologie* (18) as the three major sources used by authors to communicate studies on honey from the Meliponini Tribe. Another book and six journals hosted 13 to 8 documents. Besides the number of publications used for ranking by the Scopus database, visualized journal's h-index, quartile and impact score published by indexing agencies covered the overall impact of each journal. This information was not available for the two books in Table SV. Most top ten journals are Q1, their h-index varied from 10 to 281 for *Food Chemistry*, the highest h-index and impact factor (8.69) was ranked fourth in number of publications.

Recent editorial developments by the *Journal of Apicultural Research* and *Apidologie*, select manuscripts on chemical quality of honey in a biological context of their biogeographic distribution, botanical biodiversity, microbial origin of the chemical metabolites, controlled experiments, post-harvest processing, and shelf life, among others. The sensory attributes of honey related to derived nectar or honeydew chemical compositions, and stingless bee species was a chapter in the *Pot-honey* book, besides other eleven chapters on chemical quality of pot-honey.

Bibliometrix provided the most relevant source titles (Figure S11) according to their ranking based on number of publications in chemical quality of pot-honey or stingless bee honey research. In this figure 10 source titles were visualized exactly like they were retrieved for Table SV from the Scopus database.

The sources used by authors to disseminate their research on pot-honey or stingless bee honey could not be mapped by Bibliometrix, for this reason, the VOSviewer software was used to present Figure 1. More sources were visualized using cluster size 3 in the upper map (Figure 1a), but not all the nodes hosted visible corresponding sources. The largest nodes of the *Journal of Apicultural Research* and of the book *Pot-Honey. A Legacy of Stingless Bees* were very close. The latter was not written in the map, besides two smaller yellow nodes also overlapped by source titles of neighboring nodes. Therefore, increasing the cluster size to 4, reduced the number of mapped sources, but improved the visualization of all sources in each node (Figure 1b), including the *Pot-Honey* book (10 years, since 2013) forming a cluster of the largest violet nodes with the specialized *Journal of Apicultural Research* (60 years, since

1962) and *Apidologie* (51 years, since 1971) –in agreement with the ranked top 3 sources in Table SV–. The journals missed before in the two yellow nodes were *Food Research* to the left, and *Grana* to the right. *Molecules* was the largest yellow node, followed by *Food Research International*. *Sociobiology*, *Food Chemistry*, *LWT*, *Journal of Food Composition and Analysis*, and *Malaysian Applied Biology* formed the second largest orange cluster. From the 19 nodes visualized in the Figure 1b lower map, 17 were journals, and two of them were books, including the *Stingless Bee's Honey from Yucatan Culture, Traditional Uses and Nutraceutical Potential*.

The source title dynamics along the years were plotted in Figure S12 with cumulative occurrences of seven sources –4 journals and 2 books– in the six decades (1962-2022). Two of them initiated a steady growth in 1993, the two books had an exponential growth the year of publication, 2013 *Pot-honey. A legacy of stingless bees*, and 2016 *Stingless bee's honey from Yucatan: Culture, traditional uses and nutraceutical potential*, then flattened into a plateau because obviously after the published chapters, they were not receiving new periodical articles like journals. Until 2020, the *Pot-honey* book was the top source, then it became the second source as found in Table SV. The *Journal of Apicultural Research* was leading followed by *Apidologie*, *Food Chemistry*, *Sociobiology*, and *Molecules*.

Another important graph was provided by Bibliometrix for sources clustering through Bradford's Law. Core sources were visualized according to the number of articles in Figure S13 Bradford's law shows the dispersion of scientific literature, No. journals/No. documents on a topic. Most articles are concentrated in few journals, and few remaining articles are dispersed in many other journals, or chapters in books. *Journal of Apicultural Research* (30 articles), *Pot-honey. A legacy of stingless bees* (24 chapters), *Apidologie* (18), *Food Chemistry* (13), *Sociobiology* (11), *Molecules* (10), and other source titles less than 10 articles in six decades (1962-2022) of publications on chemical quality of pot-honey or stingless bee honey.

A further plot on source local impact by H-index was visualized in Figure S14, showing the first position (13) for the journals *Apidologie* and *Journal of Apicultural Research*, the second position (10) for the book *Pot-honey. A legacy of stingless bees*, and third (8) for *Food Chemistry*.

Major Scopus subject areas in pot-honey or stingless bee honey scientific publications

The top-ten most relevant subject areas for pot-honey or stingless bee honey research publications (1962-2022) were: 1. Agricultural and Biological Sciences (377) was the most interesting subject area of scientific publications with more than 40% of the publications, followed by 2. Biochemistry, Genetics and Molecular Biology (91), 3. Chemistry (67), 4. Environmental Science (55), 5. Medicine (55), 6. Pharmacology, Toxicology and Pharmaceutics (38), 7. Engineering (28), 8. Immunology and Microbiology (24), 9. Social Sciences (24), and 10. Multidisciplinary (22).

Major funding sponsors for research on pot-pollen and stingless bee honey

The number of pot-honey and stingless bee honey projects funded by sponsors in the Scopus database was inserted in brackets. Brazil reached 5/10 sponsors with 140 projects, followed by Malaysia with 4/10 sponsors for 85 projects, and Argentina with 11 projects. The ten funding sponsors supporting more projects on stingless bee honey research accross the globe were: Conselho Nacional de Desenvolvimento Científico e Tecnológico from Brazil (61), Coordenação de Aperfeiçoamento de Pessoal de Nível Superior from Brazil (56), Ministry of Higher Education, Malaysia (50), Universiti Putra Malaysia (18), Consejo Nacional de Ciencia y Tecnología from Argentina (11), Universiti Kebangsaan Malaysia (9), Fundação de Amparo à Pesquisa do Estado de São Paulo (8), Fundação de Amparo à Pesquisa do Estado do Amazonas (8), Universiti Teknologi Malaysia (8), and Fundação de Amparo à Pesquisa do do Estado de Minas Gerais (7).

Removing authors' keywords retrieved from the Scopus database, not visible in the dataset documents

In diverse datasets authors's keywords resulted with additions not included in the documents of the dataset. These observations were illustrated in Figure S15 comparing the Tree maps obtained with Bibliometrix using the Scopus database author's keywords as retrieved (upper Tree), and after removing the authors' keywords not used by the authors of the dataset in their documents (lower Tree). These words were: Animal, animals, article, female, male, human, nonhuman, and unclassified drug. The untransformed Tree showed a different composition of keywords, but the transformed tree shows the use of authors' keywords in their documents on chemical quality of pot-honey or stingless bee honey (1962-2022). Percentages of authors' keyword use were honey (12%) and stingless bee honey (7%) are 19%. Authors would advise to use stingless bee honey for this topic, which has an accepted acronym for the norms SBH translated into Spanish abejas sin aguijón ASA, Portuguese abelhas sem ferrão ASF, and Chinese无刺蜂蜂蜜。 no acronym. Stingless bees (12%) and stingless bees (9%) account 17%. Meliponini (5%) and meliponiculture (4%). Togheter these keywords were used by authors in 45% of their publications in this topic. A A 9% for antioxidant, melipona, and propolis (3%) each, 12% for apis mellifera, meliponinae, pollen, antimicrobial activity, flavonoids, and physic chemical properties (2%) each, 10% for antibacterial, antibacterial activity, physicochemical, chemometrics, kelulut honey, phenolic compounds, phenolics, pollen analysis, antmicrobial, and adulteration (1%) each, 3% for the stingless bees kelulut, melipona beecheii, and heterotrigona itama (1%) each, and one country Venezuela (1%).

Evolution of the published research on chemical quality of pot-honey or stingless bee honey

Quantitative evaluation on the data related to the number and citation of publications was applied to assess growth, maturity, leading authors, conceptual and intellectual maps, trends and evolution of the topic using the author's keywords. In Figure S16 the thematic evolution on chemical quality of pot-honey or stingless bee honey was visualized from the conceptual variable. The period 1962 to 2018 was characterized by author's keywords meliponinae, feeding behavior, honey and staphilococcus aureus, evolving to a focus on honey and stingless bee in 2019-2022.

The evolution of authors' keywords was also visualized with VOSviewer version 1.6.18 for the decade (2010-2020) in the map of Figure S17. After querying from Scopus as previously informed, a bibliographic search from World of Science (WoS) database using the same query string the 21st December 2022 did not generate keywords not used by the authors, as observed in the Scopus database. The 61 most frequent author's keywords used since the year 2010 (violet) until the year 2020 (yellow) were mapped in 8 clusters, and showed the variations of keywords used across time. This evolution consisted on trends of keywords' use from the largest nodes for stingless bees (violet), honey, stingless bee and meliponini (sea green), physicochemical properties (bright green), stingless bee honey (lime green), and kelulut honey (yellow) showing the temporal trend of major keywords. Indeed, scientists used to separate keywords honey and stingless bees or Meliponinae (violet) later named Meliponini (sea green) tribe. The creation of the initial norms to regulate the honey produced in cerumen pots possibly motivated to consider it one keyword self-containing the honey and the honey making bees, thus stingless bee honey has been gaining visibility as a recent authors' keyword (See Figure S17). Similarly, the Kelulut honey with a yellow node indicated the most recent color in the scale for the year 2020, after the creation of the kelulut honey norm (Department of Standards Malaysia, 2017). To the left side of the map, the entomological keywords included taxonomy, morphology, hymenoptera, apidae, bees, honey bee, honey bees, honey bee, apis, and apis mellifera; trigona (violet) positioned in the center and melipona beecheii (yellow) to the right. The right side of the map was for keywords used in the studies of chemical quality, such as honey quality, chemical composition, physicochemical analysis, physicochemical properties, adulteration, multivariate analysis, chemometrics, phenolic compounds, phenolics, flavonoids, polyphenols, food analysis, food composition; and the keywords related with honey bioactivity, like antioxidant, anti-inflammatory, antibacterial activity, antimicrobial activity, antioxidant activity; and also pollen analysis. The hplc and the scanning electron microscopy were the two techniques. Two countries were used as authors' keywords in the past (violet) for this dataset, brazil and venezuela; and one biome, caatinga. Propolis central small node (sea green). Meliponiculture was positioned in a lower central keyword small node (lime green). The 61 nodes were distributed in 8 clusters: Cluster 1 apis mellifera, beekeeping, brazil, floral resources, foraging, honey bees, melipona beecheii, meliponiculture, melissopalynology, pollen, social insects, stingless bees, and tetragonisca angustula; cluster 2 antibacterial activity, antioxidant activity, apis, botanical origin, flavonoids, hplc, melipona, meliponini,phenolic compounds, propolis, and trigona; cluster 3 apidae, bees, honey bee, honey bee, hymenoptera, midgut, morphology, pollination, stingless bee, taxonomy, and tool use; cluster 4 adulteration, antimicrobial activity, chemical composition, chemometrics, honey, honey quality, multivariate analysis, physicochemical properties, and stingless bee honey; cluster 5 anti-inflammatory, antibacterial, antimicrobial, antioxidant, Kelulut honey, and scanning electron microscope; cluster 6 native bees, phenolics, physicochemical analysis, pollen analysis, andvenezuela; cluster 7 food analysis, food composition, polyphenols, and cluster 8 caatinga, meliponinae, and yeast.

Attempts and global expansion of stingless bee honey norms

Venezuelan attempts to create a norm for stingless bee honey were published in the Spanish specialized magazine Vida Apícola (2022) but the editor removed the table of results. Therefore, Revista de la Facultad de Farmacia would be more adequate to disseminate the complete manuscript. The aborted project of the Ecuadorian pot-honey norm after a year of monthly meetings, left residual references of stingless bees in the revised norm for *Apis mellifera* honey one of the authors would have never attended, but justified for a pot-honey norm (P. Vit, personal observations). The last draft of the Ecuadorian pot-honey norm project INEN 2015 is available in the institutional repository at Universidad de Los Andes, hosted in the web page Stingless Bee Honey, Norms (INEN, 2015). The German chemical quality analysis of Ecuadorian pot-honey by Intertek and QSI were not included in the draft by INEN authorities. The *Apis mellifera* honeys were not sampled by Agrocalidad for updating the Ecuadorian honey standards with private analytical financial coverage by Schullo S.A. Other attempts and new proposals from Australia, Bolivia, Brazil, Colombia, Costa Rica, China, El Salvador, Guatemala, India, Indonesia, Kenya, Mexico, Peru, and the Philippines, may find endurance to pursue National Standards for honey produced in pots by stingless bees, successfully achieved by Malaysia in 2017, and Argentina in 2020.